Section 3

Nuclear Energy

Objectives

After completing the lesson, students will be able to

E.5.3.1 Describe what happens during a nuclear fission reaction.

E.5.3.2 Explain how a nuclear power plant produces electricity.

E.5.3.3 Describe what takes place in a nuclear fusion reaction.

Target Reading Skill

Comparing and Contrasting Explain that comparing and contrasting information shows how ideas, facts, and events are similar and different. The results of the comparison can have importance.

Answers

Possible answers: Similarities—both types of reactions release large amounts of energy and involve small losses of mass; differences—fission uses uranium and splits nuclei, fusion uses hydrogen and combines nuclei.

All in One Teaching Resources

- Transparency E46

Preteach

Build Background Knowledge

L2

Picturing an Atom

Ask several students to come to the board, draw what they think an atom looks like, and label its parts. Encourage the rest of the class to discuss the drawings and suggest corrections or additions. You can return to the diagrams later in the lesson.

Section 3

Nuclear Energy

Reading Preview

Key Concepts

- What happens during a nuclear fission reaction?
- How does a nuclear power plant produce electricity?
- How does a nuclear fusion reaction occur?

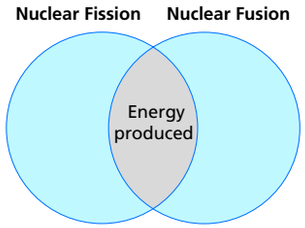
Key Terms

- nucleus
- nuclear fission
- reactor vessel
- fuel rod
- control rod
- meltdown
- nuclear fusion

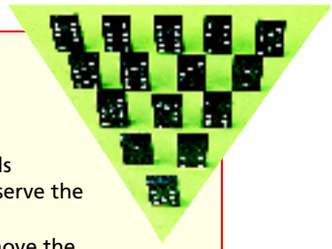
Target Reading Skill

Comparing and Contrasting

As you read, compare fission and fusion reactions in a Venn diagram like the one below. Write the similarities in the space where the circles overlap and the differences on the left and right sides.



Lab zone Discover Activity



Why Do They Fall?

1. Line up 15 dominoes to form a triangle.
2. Knock over the first domino so that it falls against the second row of dominoes. Observe the results.
3. Set up the dominoes again, but then remove the dominoes in the third row from the lineup.
4. Knock over the first domino again. Observe what happens.

Think It Over

Inferring Suppose each domino produced a large amount of energy when it fell over. Why might it be helpful to remove the dominoes as you did in Step 3?

Wouldn't it be great if people could use the same method as the sun to produce energy? In a way, they can! The kind of reactions that power the sun involve the central cores of atoms. The central core of an atom that contains the protons and neutrons is called the **nucleus** (plural *nuclei*). Reactions that involve nuclei, called nuclear reactions, result in tremendous amounts of energy. Two types of nuclear reactions are fission and fusion.

Nuclear Fission

Nuclear reactions convert matter into energy. As part of his theory of relativity, Albert Einstein developed a formula that described the relationship between energy and matter. You have probably seen this famous equation: $E = mc^2$. In the equation, the E represents energy and the m represents mass. The c, which represents the speed of light, is a very large number. This equation states that when matter is changed into energy, an enormous amount of energy is released.

▲ **Albert Einstein 1879–1955**

Lab zone Discover Activity

Skills Focus Inferring

Materials 15 dominoes

Time 10 minutes

Tips Make sure students place the dominoes with less than a domino-length space between rows.

L2

Expected Outcome In Step 2, all 15 dominoes will topple as those in one row fall back against those in the next row. With the third row removed in Step 4, the last two rows will remain standing.

Think It Over Removing the third row would stop the production of energy after a certain point.

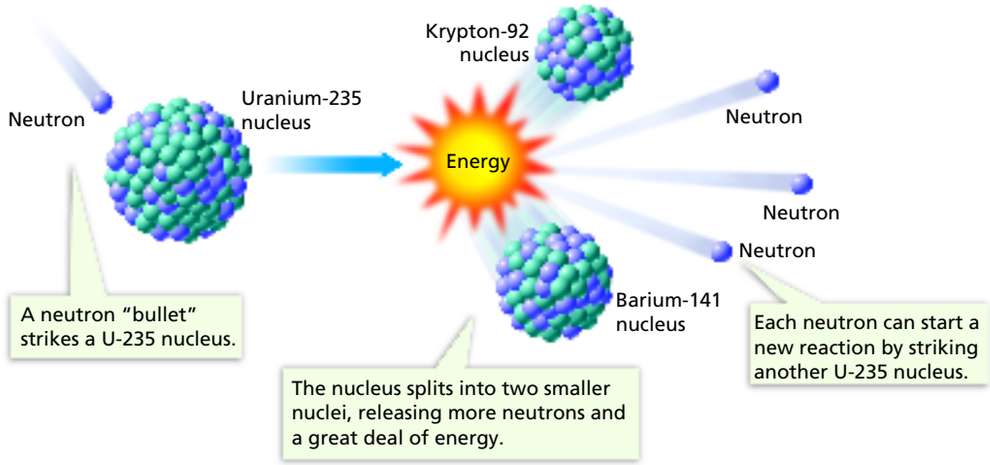


FIGURE 12
Nuclear Fission
A great deal of energy is released in a nuclear fission reaction.
Interpreting Diagrams *How does a nuclear fission reaction begin?*

Fission Reactions **Nuclear fission** is the splitting of an atom's nucleus into two smaller nuclei. The fuel for the reaction is a large atom that has an unstable nucleus, such as uranium-235 (U-235). A neutron is shot at the U-235 atom at high speed. **When the neutron hits the U-235 nucleus, the nucleus splits apart into two smaller nuclei and two or more neutrons.** The total mass of all these particles is a bit less than the mass of the original nucleus. The small amount of mass that makes up the difference has been converted into energy—a lot of energy, as described by Einstein's equation.

Meanwhile, the fission reaction has produced three more neutrons. If any of these neutrons strikes another nucleus, the fission reaction is repeated. More neutrons and more energy are released. If there are enough nuclei nearby, the process repeats in a chain reaction, just like a row of dominoes falling. In a nuclear chain reaction, the amount of energy released increases rapidly with each step in the chain.

Energy From Fission What happens to all the energy released by these fission reactions? If a nuclear chain reaction is not controlled, the released energy causes a huge explosion. The explosion of an atomic bomb is an uncontrolled nuclear fission reaction. A few kilograms of matter explode with more force than several thousand tons of dynamite. However, if the chain reaction is controlled, the energy is released as heat, which can be used to generate electricity.

Reading Checkpoint **What happens if a nuclear chain reaction is not controlled?**

Lab zone Skills Activity

Calculating

A pellet of U-235 produces as much energy as 615 liters of fuel oil. An average home uses 5,000 liters of oil a year. How many U-235 pellets would be needed to supply the same amount of energy?

Lab zone Skills Activity

Skills Focus Calculating

Materials calculator (optional)

Time 5 minutes

Tips If needed, help students determine how to calculate the answer (divide 5,000 by 615).

L2 **Expected Outcome** About 8 pellets would be needed.

Extend Suggest that each student estimate how many homes are in his or her neighborhood and then calculate how many pellets would be needed to supply energy to all those homes for a year.

learning modality: logical/mathematical

Instruct

Nuclear Fission

Teach Key Concepts L2

Energy From Fission

Focus Tell students that in a fission reaction, the nucleus of a large atom is split into smaller nuclei and the small amount of mass lost is converted into a great deal of energy.

Teach Tell students that an atom's nucleus splits when it is hit by a neutron. Ask: **When neutrons are released in a fission reaction, what happens to them?** *(They can strike other nuclei and cause additional fission reactions.)* **When does a nuclear chain reaction take place?** *(When there are enough nuclei nearby as neutrons and energy are released, increasing numbers of fission reactions occur.)*

Apply Ask: **How is it that nuclear chain reactions can generate electricity as well as cause atomic bombs to explode?** *(Electricity is generated in controlled nuclear chain reactions; nuclear bombs explode in uncontrolled nuclear chain reactions.)* **learning modality: logical/mathematical**

Independent Practice L2

All in One Teaching Resources

- Guided Reading and Study Worksheet: *Nuclear Energy*
- Transparency E47

Student Edition on Audio CD

Monitor Progress L2

Answers

Figure 12 A neutron "bullet" strikes an atom.

Reading Checkpoint An uncontrolled nuclear chain reaction results in an explosion.

Nuclear Power Plants

Teach Key Concepts L2

How Fission Generates Electricity

Focus Remind students that a nuclear power plant functions like other power plants: a heat source—in this case, fission—changes water into steam that powers turbines.

Teach Have students review Figure 14. Ask: **What are the three main components involved in creating power from nuclear fission?** *(Reactor vessel, heat exchanger, and generator)* **What are the differences between fuel rods and control rods?** *(Fuel rods contain the uranium involved in fission reactions. Control rods are made of cadmium metal that absorbs neutrons released in fission. They are placed between fuel rods to control fission reactions.)*

Apply Ask: **Name two other energy sources that create steam to turn turbines that generate electricity at a power plant.** *(Any two: fossil fuels, especially coal; solar power; geothermal energy)* **learning modality: visual**

All in One Teaching Resources

- Transparency E48

Help Students Read L1

Relating Cause and Effect Help students understand the process of producing power from nuclear fusion by asking them to analyze the cause-and-effect relationships in the process. Have them create a flowchart beginning with nuclear fusion and ending with electric current going to power lines.

FIGURE 13
Nuclear Power
Nuclear power plants generate much of the world's electricity. The inset shows autunite, one of the ores of uranium. The uranium fuel for nuclear power plants is refined from uranium ores.

Nuclear Power Plants

Controlled nuclear fission reactions take place inside nuclear power plants. Nuclear power plants generate much of the world's electricity—about 20 percent in the United States and more than 70 percent in France. **In a nuclear power plant, the heat released from fission reactions is used to change water into steam. The steam then turns the blades of a turbine to generate electricity.** Look at the diagram of a nuclear power plant in Figure 14. In addition to the generator, it has two main parts: the reactor vessel and the heat exchanger.

Reactor Vessel The **reactor vessel** is the part of the nuclear reactor where nuclear fission occurs. The reactor contains rods of U-235, called **fuel rods.** When several fuel rods are placed close together, a series of fission reactions occurs.

If the reactor vessel gets too hot, control rods are used to slow down the chain reactions. **Control rods,** made of the metal cadmium, are inserted between the fuel rods. The cadmium absorbs neutrons released during fission and slows the speed of the chain reactions. The cadmium control rods can then be removed to speed up the chain reactions again.

Heat Exchanger Heat is removed from the reactor vessel by water or another fluid that is pumped through the reactor. This fluid passes through a heat exchanger. There, the fluid boils water to produce steam, which runs the electrical generator. The steam is condensed again and pumped back to the heat exchanger.

Reading Checkpoint **What is the purpose of a control rod?**

The Risks of Nuclear Power At first, people thought that nuclear fission would provide an almost unlimited source of clean, safe energy. But accidents at nuclear power plants have led to safety concerns. In 1986, the reactor vessel in a nuclear power plant in Chernobyl, Ukraine, overheated. The fuel rods generated so much heat that they started to melt, a condition called a **meltdown.** The excess heat caused a series of explosions, which injured or killed dozens of people. In addition, radioactive materials escaped into the environment.

Accidents can be avoided by careful planning and improved safety features. A more difficult problem is the disposal of the radioactive wastes. Radioactive wastes remain dangerous for many thousands of years. Scientists must find a way to store these wastes safely for a long period of time.

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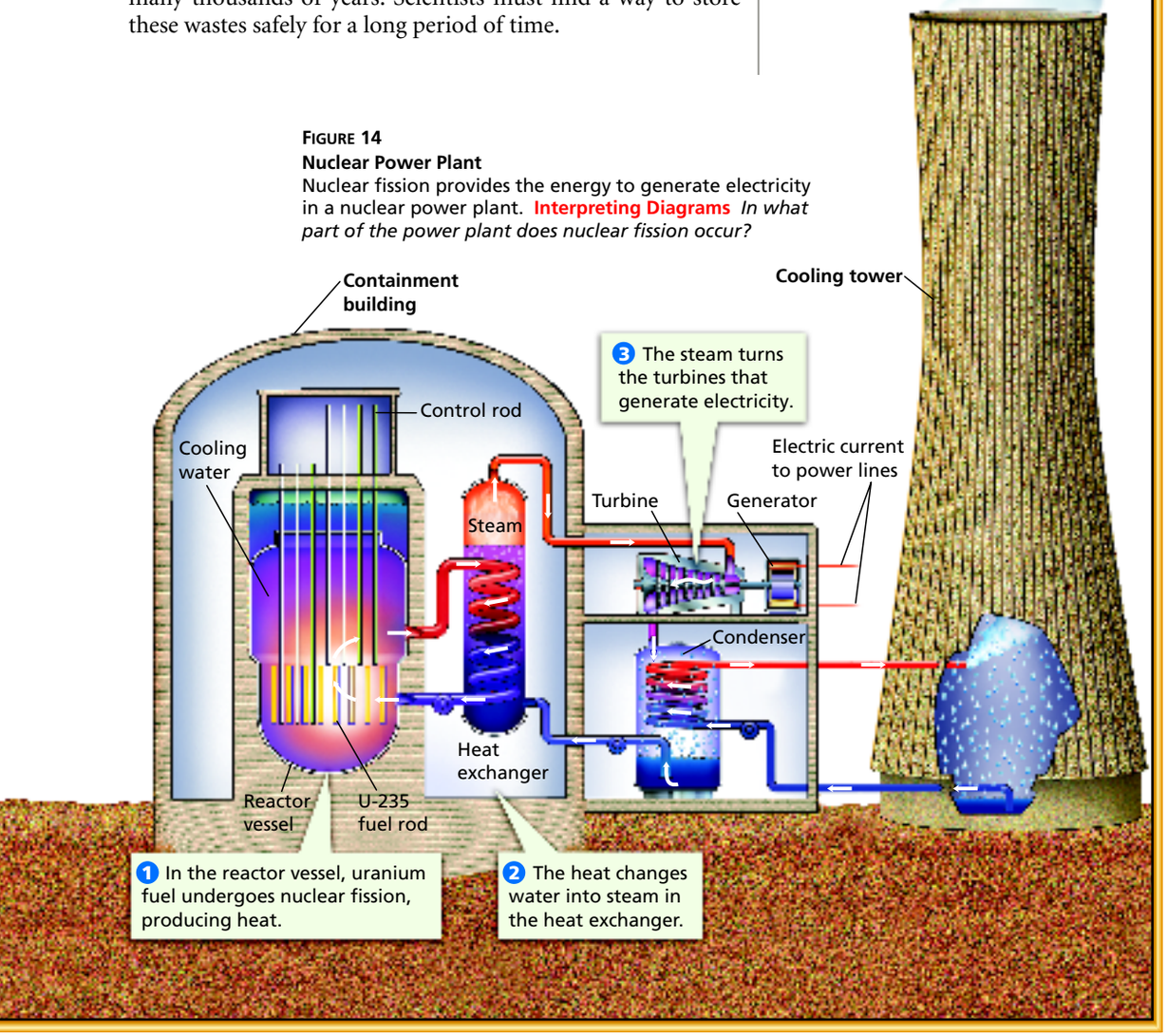
Students explore how a nuclear power plant works.

FIGURE 14
Nuclear Power Plant
Nuclear fission provides the energy to generate electricity in a nuclear power plant. **Interpreting Diagrams** *In what part of the power plant does nuclear fission occur?*



Lab zone **Build Inquiry** L1

Nuclear Power Accidents

Materials large world map

Time 15 minutes

Focus Explain that radioactive fallout from the Chernobyl accident was spread by air currents.

Teach Display the map, and let volunteers locate Chernobyl (51° N, 30° about 130 km north of Kiev). Tell students that the force of the 1986 explosion carried radioactive materials high into the atmosphere, where they spread across the Northern Hemisphere and then settled back to Earth in what is called fallout. The heaviest fallout occurred in Ukraine, Belarus, Sweden, Norway, Denmark, France, and Switzerland. In addition, Finland, Lithuania, Germany, Poland, the Czech Republic, Slovakia, Austria, Hungary, Italy, and Great Britain suffered moderate fallout. Let students find all these countries on the map. Ask: **Which affected country was farthest from Chernobyl?** *(Great Britain)*

Apply Ask: **What does this tell you about the dangers of nuclear power plants?** *(An accident can affect a huge area.)* **learning modality: visual**

Differentiated Instruction

Gifted and Talented L3
Identifying Nuclear Accidents
Challenge students to use reference books or online sources to learn the typical temperatures reached in a nuclear power plant's reactor vessel and then find the temperatures reached in the Chernobyl accident. Ask students to investigate and report on the occurrence of other nuclear accidents, such as Three Mile Island.
learning modality: logical/mathematical

Monitor Progress L2

Oral Presentation Call on students at random to each explain a step in the process of how a nuclear power plant converts nuclear energy to electricity.

Answers
Figure 14 The reactor vessel

Reading Checkpoint Control rods absorb neutrons released during fission, thus slowing the chain reactions.

The Quest to Control Fusion

Teach Key Concepts L2

Nuclear Fusion

Focus Explain that fusion has great potential as an energy source, but we currently lack the technology to use it.

Teach Ask: **What are three advantages of fusion over fission?** *(Fusion's fuel source, water, is readily available; fusion would produce more energy per unit of atomic mass and less radioactive waste.)*

Apply Ask: **How are fission and fusion reactions alike?** *(Mass is lost, and energy is created.)* **learning modality: verbal**

All in One Teaching Resources

- Transparency E49

Monitor Progress L2

Answers

Figure 15 A neutron plus energy

Assess

Reviewing Key Concepts

1. a. the splitting of an atom's nucleus into two smaller nuclei **b.** A neutron strikes a U-235 nucleus, which splits into two smaller nuclei and releases two or more neutrons and energy. **c.** nonrenewable because it depends on nonrenewable uranium

2. a. controlled nuclear fission chain reaction **b.** Thermal energy released by a fission reaction is used to boil water, producing steam that turns the blades of a turbine to generate electricity. **c.** Excess heat could build up and cause a meltdown, leading to explosions and release of radioactive material.

3. a. Two hydrogen nuclei combine to create a helium nucleus. **b.** Lost mass converts to energy. **c.** The high temperatures and pressures required for a fusion reaction make the construction of a fusion reactor impractical with today's technology.

Reteach L1

Use Figures 12 and 15 to compare how nuclear fission and fusion produce energy.

All in One Teaching Resources

- Section Summary: *Nuclear Energy*
- Review and Reinforce: *Nuclear Energy*
- Enrich: *Nuclear Energy*

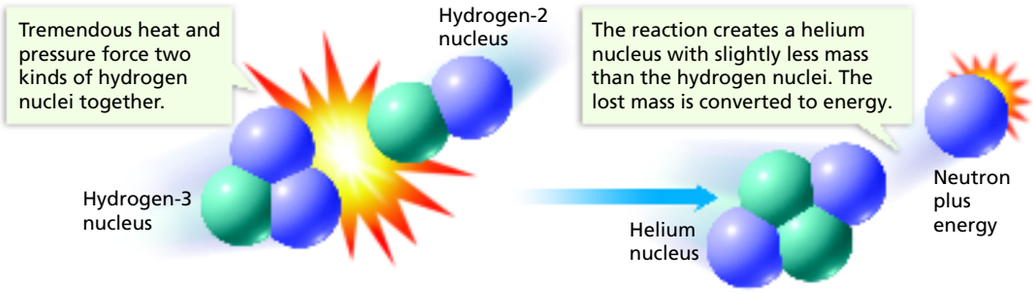


FIGURE 15
Nuclear Fusion
In nuclear fusion, two hydrogen nuclei are forced together, forming a helium nucleus, a neutron, and energy.
Interpreting Diagrams *What is released during a fusion reaction?*

The Quest to Control Fusion

Nuclear fusion is the combining of two atomic nuclei to produce a single larger nucleus. **In nuclear fusion, two hydrogen nuclei combine to create a helium nucleus, which has slightly less mass than the two hydrogen nuclei. The lost mass is converted to energy.**

Nuclear fusion could produce much more energy per unit of atomic mass than nuclear fission. The fuel for a fusion reactor is readily available—water contains one kind of hydrogen needed for fusion. Nuclear fusion should also produce less radioactive waste than nuclear fission. Unfortunately, the pressure and temperature required for a reaction make the construction of a fusion reactor impractical at this time.

Section 3 Assessment

Target Reading Skill **Comparing and Contrasting** Use the information in your Venn diagram to answer Questions 1 and 3 below.

Reviewing Key Concepts

1. **a.** **Defining** What is nuclear fission?
   b. **Sequencing** Describe the steps that occur in a nuclear fission reaction.
   c. **Classifying** Is nuclear fission a renewable or nonrenewable energy source? Explain.
2. **a.** **Identifying** What type of nuclear reaction produces electricity in a nuclear power plant?
   b. **Explaining** Explain how electricity is produced in a nuclear power plant.
   c. **Predicting** What might happen in a nuclear power plant if too many control rods were removed?
3. **a.** **Reviewing** Define nuclear fusion.
   b. **Relating Cause and Effect** How is energy produced during a nuclear fusion reaction?
   c. **Inferring** What is preventing fusion energy from filling our current energy needs?

Lab zone At-Home Activity

Shoot the Nucleus With a family member, make a model of a nuclear fission reaction. Place a handful of marbles on the floor in a tight cluster, so that they touch one another. Step back about a half meter from the marbles. Shoot a marble at the cluster. Note what effect the moving marble has on the cluster. Then using a diagram, explain how this event models a nuclear fission reaction.

Lab zone Chapter Project

Keep Students on Track Encourage students to make their reports concise, focusing on the major points and, when appropriate, using visual displays, such as a neat copy of the data table. Also suggest that they explain how each recommendation would reduce energy use.

Lab zone At Home Activity

Shoot the Nucleus L1 Before students present the activity at home, have them review Figure 12. Instruct them to determine what the marble being shot at the cluster represents. *(a neutron being shot at a nucleus)*